APPENDIX G3

GEOLOGY

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This appendix discusses the geologic conditions and hazards that may be encountered during the construction and implementation of the alternatives for the San Luis Drainage Feature Re-evaluation. This section focuses on two geomorphic regions within California: San Joaquin Valley and the Coast Ranges, which may influence the selection of a preferred alternative due to the geologic conditions and potential geologic hazards associated with these regions.

Specific soil types within the San Joaquin Valley, Sacramento Delta region, or the Coast Range region will be discussed in more detail once the preferred alternative has been chosen and facilities have been sited. However, for background purposes, the surface soils in the San Joaquin Valley mostly consist of Holocene age unconsolidated sediments. Beneath the unconsolidated Holocene sediments are Pleistocene to Cretaceous age marine and non-marine sediments. Marine sediments generally consist of fine-grained clays and silts and the non-marine sediments usually consist of coarse-grained sands and gravels.

G3.1 AFFECTED ENVIRONMENT–SAN JOAQUIN VALLEY

G3.1.1 Geologic Conditions

The existing San Luis Drain is situated near the western border of San Joaquin Valley, which comprises the southern region of the Great Valley Geomorphic Province. The Great Valley Province is one of the largest agricultural basins in the world and is split into two regions including Sacramento Valley in the northern section and San Joaquin Valley in the southern section. The boundary between the northern and southern regions of the Great Valley is denoted by the Delta.

Geologically, San Joaquin Valley is a topographic and structural basin with the axis offset to the west, and a gentle topographic downward slope to the north. The valley encompasses approximately 10,000 square miles and is bounded to the east by the Sierra Nevada Range, to the west by the Coast Ranges, to the south by the Tehacapi Mountains, and to the north by the Delta. The Sierra Nevada is composed of igneous and metamorphic rocks of pre-Tertiary age. The granitic rocks of the Sierra Nevada comprise the basement complex beneath the Great Valley. Overlying the basement complex is approximately 30,000 feet of Late Cenozoic sedimentary deposits in central and northern San Joaquin Valley. The sedimentary units are the result of erosion from the Sierra Nevada and deposition from ancient inland seas that once occupied the area. The Coast Ranges contain folded and faulted sedimentary rocks of Mesozoic and Cenozoic age, which are similar to those rocks that underlie San Joaquin Valley at depth, and nonconformably overlie the basement complex (Norris and Webb 1990). The Coast Range geology will be explained further in Section G3.2.

Soil types in central San Joaquin Valley tend to consist mostly of unconsolidated silty sands, poorly graded sands, clayey sands, silts, and sandy clays at shallow depths. The silty sands, clayey sands, and poorly graded sands tend to be the major water-bearing units beneath the valley. To a lesser extent, groundwater has been encountered in sandy silt and sandy clay layers, but tend to be poor groundwater-producing zones. Organic soils tend to make up the upper 10 feet of the valley in areas; however, through the intensive farming conducted in the region, the organic soils are missing or vacant in areas south of the Delta. Along the western and southern boundaries of the valley, farming in areas has ceased due to the buildup of salts and selenium in the soil. Concentrations of salts and selenium within the western and southern areas of the valley would likely increase over time should the treatment and drainage of irrigation water within these areas not be implemented.

Coarser sediments are mostly located on the eastern half of the valley, from fluvial processes, which have created large alluvial fans that extend from the Sierra Nevada to the trough (topographic low point) of the valley (Poland and Lofgren 1984). The west side of San Joaquin Valley receives less rainfall due to the rainshadow effect from the Coast Ranges and, therefore, the soils are generally more fine-grained.

The Delta region consists of a low triangular area between the city of Sacramento to the north, the city of Stockton to the south, and Suisun Bay to the west. The Delta is located approximately 50 miles from the Pacific Ocean and is currently growing inland as sediments are being deposited around the margins. Recent studies indicate that the Delta grows and recedes during periods of high and low sea levels (warming cycles and ice ages). The sediments deposited in the Delta are a mix of glacially derived deposits and marine deltaic deposits (Norris and Webb 1990).

G3.1.2 Hydrogeologic Conditions

The central and northern San Joaquin Valley groundwater-bearing units are comprised of several interbedded and unconsolidated layers of coarse- and fine-grained sediments, which can extend up to 30,000 feet below ground surface. The groundwater-bearing sedimentary deposits beneath the valley can be subdivided into two principal hydrologic units: an upper unit and a lower unit. The upper unit consists of a semiconfined aquifer system, which extends from the ground surface to the top of the Corcoran Clay Unit, at depths ranging from the ground surface to approximately 900 feet below the ground surface. The lower unit is considered to be a confined aquifer, which extends from below the Corcoran Clay Unit to the deep saline groundwater-bearing units and ranges in thickness between 200 and 2,000 feet. The Corcoran Clay Unit has an average thickness of 65 feet and is the principal confining layer beneath nearly half of San Joaquin Valley (Poland and Lofgren 1984).

Drainage of water into northern San Joaquin Valley which includes the San Joaquin, Merced, Tuolomne, Stanislaus, and Calaveras rivers is directed to the Delta. In central San Joaquin Valley, the Kings, Kaweah, and Tule rivers naturally drain toward a large basin located between the towns of Kettleman City and Stratford, which until recently consisted of Tulare Lake. Within the southern end of San Joaquin Valley, the Kern River until recently drained into Lake Buena Vista. Tulare Lake and Lake Buena Vista were both seasonal lakes. Water from the rivers that formed both of the lakes has been diverted for agricultural use, through flood control measures (i.e., dam and canal construction). The land that comprised Tulare Lake and Lake Buena Vista is now used for growing crops.

Overdraft of shallow groundwater resources within San Joaquin Valley began in the middle 1920s when an estimated 2,025,000 af was pumped from the shallow subsurface strata for irrigation purposes. The amount of overdraft continued to increase and by the 1940s an estimated 3,000,000 af was removed from the shallow aquifers on a yearly basis. By 1966 the amount of groundwater overdraft exceeded 9,720,000 af a year (Poland and Lofgren 1984). Through the importation of large amounts of surface water beginning in 1968 from the California Aqueduct, and other irrigation projects, overdraft of the groundwater supplies decreased sharply.

G3.1.3 Potential Geologic Hazards

G3.1.3.1 Land Subsidence

Land subsidence in San Joaquin Valley became a major issue beginning in the late 1960s. Overdrafting of shallow groundwater resources has caused the water table to drop from just below the surface in many areas to nearly 100 feet below ground surface in central San Joaquin Valley and over 200 feet in southern San Joaquin Valley. Land subsidence has occurred on nearly 5,200 square miles of land, (approximately 50 percent of San Joaquin Valley land mass), and ground-surface elevations in areas have dropped as much as 30 vertical feet in the last 80 years (Poland and Lofgren 1984).

Three types of land subsidence have been documented in the valley: (1) subsidence due to the compaction of aquifer units from excessive withdrawal of groundwater; (2) hydrocompaction, subsidence due to the compaction of fine-grained moisture-deficient deposits when water is applied; and (3) subsidence due to the extraction of oil deposits beneath the surface (Poland and Lofgren 1984). The first two types of subsidence described are most commonly encountered along the existing San Luis Drain and the potential route for the San Luis Drain extension.

Overdrafting of groundwater supplies has been occurring since the middle 1920s when agriculture became the main industry in San Joaquin Valley. Shallow groundwater was easy to tap into. With the invention of the electric pump and abundant water supplies, farmers were encouraged to convert the native land and grow more crops on a yearly basis. The continued pumping of groundwater eventually caused a reduction in pore pressure within the water-bearing, coarse-grained sediments beneath the valley. Through the years, more groundwater was pumped and used for irrigation than what was naturally recharged through yearly flooding and precipitation. As the water was drained from the aquifer, the sediments compacted and permanently reduced the pore space within the formation. The compaction of these coarse-grained sedimentary units caused the majority of the land subsidence in San Joaquin Valley. The location of the existing San Luis Drain and the route of the San Luis Drain extension trend through the areas that were heavily impacted by this type of land subsidence. However, since the importation of surface water for irrigation, the rate of land subsidence due to the draining of aquifers has declined sharply (Poland and Lofgren 1984).

Subsidence has also occurred in the Delta region. The area was originally covered by peat bogs, which were removed for agricultural purposes. The removal of the peat through oxidation/burning, wind-blown fine-grained sediments, and aquifer dewatering has lowered the ground surface in the Delta area by as much as 23 feet. Large dikes have been constructed to hold back yearly floodwaters of the Sacramento, American, and San Joaquin rivers. However, the potential conveyance alignment for the Delta Disposal Alternatives appears to be mostly located to the south and west of the areas impacted by the land subsidence in the Delta region (Norris and Webb 1990).

To a lesser extent, hydrocompaction has occurred in several localized areas along western San Joaquin Valley. Hydrocompaction occurs after fine-grained clay sediments deposited above the groundwater table via mud flows are dried out due to low rainfall. Once water is applied for the first time, the clay bond in these sediments weakens and the fine-grained deposits compact. Hydrocompaction has occurred along approximately 40 miles of the California Aqueduct, which trends along western San Joaquin Valley and is situated near the potential alignment of the Delta aqueduct and the San Luis Drain extension. Prior to the construction of the California Aqueduct, the fine-grained soils along the proposed route were watered thoroughly so that the soils would compact (Poland and Lofgren 1984).

Subsidence due to the extraction of oil deposits occurs primarily in southern San Joaquin Valley (Kern County) and it appears to only happen in localized areas where large amounts of oil have been pumped from the underlying strata.

G3.1.3.2 Faulting

San Joaquin Valley is probably the most seismically stable region of California due to being underlain by the granitic bedrock from the Sierra Nevada. The San Andreas fault system is one of the most active fault systems in the world and will be described in more detail in Section G3.2.

The Ortigalito fault runs along central San Joaquin Valley and has not had any measurable Holocene movement and is not considered an active fault at this time. Along northern San Joaquin Valley near the Delta is the Greenville fault zone, which trends northwest through the city of Livermore and has segments along the fault that are considered active.

The Concord fault is an active segment of the Greenville fault zone and appears to extend beneath the Delta and beyond to the north (Figure G3-1).

G3.2 AFFECTED ENVIRONMENT–COAST RANGES

G3.2.1 Geologic Conditions

The potential route of the Ocean Disposal Alternative crosses the Coast Ranges, which are situated along the western boundary of California between San Joaquin Valley and the Pacific Ocean. The Coast Ranges are about 600 miles long and comprised of a series of small mountain ranges that trend roughly parallel to the coastline of California, although the coastline has a more northerly trend. Due to the northerly trend of the coastline, the ranges intersect the Pacific Ocean in several locations and some terminate at the sea. The Coast Ranges region extends from the Santa Ynez River (near Santa Barbara) to the Oregon border (Norris and Webb 1990). The potential alignment of the Ocean Disposal Alternative crosses the southcentral portion of the Coast Ranges.

The Coast Ranges consists of a series of marine terraces underlain by granitic bedrock with overlying metamorphic sequences. The ranges have been intensely uplifted, folded, and faulted throughout history and contain profound structural discontinuities. Older Cretaceous Franciscan bedrock and Salinian bedrock have been thrusted over younger Cenozoic marine sedimentary units through the uplift of the Coast Ranges. The uplift is interpreted to be attributable to plate-tectonism involving the collision of an oceanic plate into the North American Plate. Collision and subduction of the tectonic plates resulted in the uplift of the marine terraces east of the

Figure G3-1 Fault Zone and Land Subsidence Map, Delta Disposal Alternatives

subduction zone. The subduction of the oceanic plate (probably part of the Gorda Plate, which still exists along the extreme Northern California coastline and trends north along the Oregon coastline) resulted in the formation of the Sierra Nevada. Regional volcanism is still active in the northeastern corner of California and extends up to the Cascade Range into Washington. The volcanic activity is the result of subduction of the Gorda Plate and Juan de Fuca Plate, adjacent to the north, beneath the North American Plate (Norris and Webb 1990).

River drainage of the Coast Ranges is dictated by geologic structure. The Salinas, San Antonio, and Nacimento rivers follow the elongate valleys and discharge into the Pacific Ocean in the area where the adjacent mountain ranges terminate at the sea (Norris and Webb 1990). Drainage of the northern Coast Ranges is generally the same as the southern Coast Ranges.

The soils that make up the Coast Ranges vary, based on location. The majority of the geologic units in the Coast Ranges consist of loosely to moderately consolidated sandstones, siltstones, and mudstones with some metamorphic and granitic sequences.

G3.2.2 Potential Geologic Hazards

G3.2.2.1 Faulting

The potential route of the Ocean Disposal Alternative through the Coast Ranges crosses several major fault zones including the San Andreas, Riconada, and Nacimento faults (Figure G3-2). In addition, the potential alignment also crosses several smaller faults. Fourteen smaller faults were identified along the proposed route. Of the three major fault zones identified, the San Andreas is listed as the only currently active fault zone (displacement within the last 200 years). The Riconada fault zone is reported as having Quarternary Period movement (up to 1.5 million years ago), with no evidence of Holocene Epoch (10,000 years ago) movement, and the Nacimento fault zone is represented as having Pre-Quarternary Period movement (Jennings 1994).

The San Andreas fault zone is approximately 740 miles long and trends roughly northwest from the Sea of Cortez to the Mendocino Triple Junction off of Cape Mendocino, California. The San Andreas fault zone is responsible for numerous earthquakes felt along the central coast of California. In the central Coast Ranges, the San Andreas fault gouge is thought to extend approximately 12 miles beneath the surface with most earthquakes occurring at 8.5 miles beneath the surface (Norris and Webb 1990).

The San Andreas is a right strike-slip fault that has historically exhibited significant vertical slippage in the San Gabriel Mountains, to the south of San Joaquin Valley, and in several other locations throughout California. Along the southern portion of the San Andreas fault zone, between the Salton Sea and the Sea of Cortez, the faulting action on the San Andreas changes from strike-slip movement to a divergent plate boundary. The northern end of the San Andreas is marked by the Mendocino Triple Junction, which is the boundary for the Gorda Plate, the Pacific Plate, and the North American Plate (Norris and Webb 1990).

Historic earthquakes in the southern Coast Ranges have resulted in several feet of fault line displacement occurring in a single event. In addition, the average fault creep in this area amounts to 1 to 2 centimeters per year.

G3.2.2.2 Landslides

Due to the loosely to moderately consolidated condition of the sedimentary units within the central Coast Ranges, the area is very susceptible to landslide events. Heavy amounts of precipitation can fall in a short amount of time, saturating the sediments and causing failure on steep slopes. Landslides and shallow soil slips are mostly observed in the northern Coast Ranges; however, flash-type flooding events tend to dominate the southern range and without sufficient vegetative cover (due to low rainfall annually), large-scale landslides have occurred. The Franciscan Formation is frequently associated with landslides along the Coast Ranges and accounts for the downslope transport of significant volumes of material (Norris and Webb 1990). Due to an abundant amount of serpentinite in the Franciscan Formation, serpentinite shearing is prevalent and, therefore, makes the formation more susceptible to landslides. The Ocean Disposal Alternative would cross the Franciscan Formation between the edge of the Kettleman Hills and Cottonwood Pass, and from near the summit of the Santa Lucia Range to the Pacific Ocean.

G3.3 ENVIRONMENTAL CONSEQUENCES

This section describes how the implementation of new conveyance and other facilities would be affected by the geologic hazards previously identified.

G3.3.1 Key Impact and Evaluation Criteria

The key issues involved with the construction of the alternatives are the amount of land subsidence beneath central San Joaquin Valley, the numerous active and inactive earthquake faults present along any of the potential alternative routes, and the landslide issues along the Coast Ranges.

G3.3.2 Environmental Impacts

G3.3.2.1 No Action Alternative

The existing Drain would be in use until 2009 and is subject to one documented geologic hazard, land subsidence. Two types of land subsidence are most commonly encountered along the existing San Luis Drain: reduction of pore space from over pumping of groundwater resources and hydrocompaction. Subsidence due to oil extraction has been documented in southern San Joaquin Valley near Bakersfield and should not be an issue with the No Action Alternative.

Topographically, San Joaquin Valley slopes downward in elevation toward the Delta region and the southern portion of the Drain is located at a topographically higher elevation than the northern portion. This slope allows the existing Drain to be gravity fed and does not require uphill pumping of the agricultural wastewater. It is likely that certain portions of the existing Drain have been impacted at some point by land subsidence. However, the amount of land subsidence around these portions of the existing Drain may not have been significant enough to alter the grade of the drainage route. Since the importation of surface water to this area, the rate

Figure G3-2 Fault Zone and Land Subsidence Map, Ocean Disposal Alternative

of land subsidence has diminished and should not represent a significant impact to the existing Drain by the 2009 closure date.

G3.3.2.2 Ocean Disposal Alternative

The potential route for this alternative through the Coast Ranges crosses several major fault zones including the San Andreas, Riconada, and Nacimento faults (Figure G3-2). In addition, the potential alignment also crosses several smaller faults. Fourteen smaller faults were identified along the potential route. Of the three major fault zones identified, the San Andreas is listed as the only currently active fault zone (displacement occurring within the last 200 years). Significant displacement along the San Andreas fault zone could cause the PVC-constructed aqueduct for this alternative to fail. The San Andreas fault has accounted for several intense ground accelerations associated with earthquakes in the Parkfield, California area (approximately 10 miles north of the potential route). The earthquakes measured in this area ranged from 5.75 to 6.4 on the Richter Scale between 1881 and 1966. Regarding the smaller faults identified along the potential route, it is unlikely that any of the 14 faults identified could cause a major disruption of this route. None of these smaller faults have shown measurable displacement within the last 1,600,000 years.

The potential for intense ground accelerations associated with earthquakes in the southern Coast Ranges would likely require significant engineering measures for the construction of this alternative. The engineering measures would take into account the 1- to 2-centimeter creep that occurs along the San Andreas fault zone on a yearly basis. In addition, this alternative's route would cross the Franciscan Formation between the edge of Kettleman Hills and Cottonwood Pass, and from near the summit of the Santa Lucia Range to the Pacific Ocean. The Franciscan Formation is susceptible to landslides and accounts for the majority of rock and soil material that is sent downslope during landslide events in the Coast Ranges. Significant geotechnical studies, including slope stability, and soil compaction characteristics, would have to be conducted for the pump stations on this route, especially if the locations of the pump stations are on a slope.

G3.3.2.3 Delta Disposal Alternatives

The Delta Disposal Alternatives should not be impacted by land subsidence since hydrocompaction and pore space compaction mostly occurs south of the Los Banos, California area. Their potential conveyance alignment appears to be mostly located to the south and west of the areas impacted by the land subsidence in the Delta region (Norris and Webb 1990). Subsidence due to oil resource extraction mostly occurs in southern San Joaquin Valley and is not an issue with the Delta Disposal Alternatives.

The potential conveyance does not appear to cross any major fault lines identified within central San Joaquin Valley. However, the conveyance trends roughly parallel to the San Andreas fault system located between 40 and 60 miles to the west (Figure G3-1). In addition, near San Luis Reservoir, the potential alignment appears to be approximately 15 miles east of the Ortigalito fault and trends roughly parallel to the fault zone. The Ortigalito fault has not had any measurable Holocene movement and is not considered an active fault at this time.

The possibility exists that a sizeable earthquake associated with the San Andreas fault could disrupt the Delta Disposal Alternatives' aqueduct. However, the 1989 Loma Prieta earthquake did not appear to impact the California Aqueduct in a significant manner, which is located near the potential route. Engineering methods and procedures have improved and are more stringent than when the California Aqueduct was constructed. Therefore, it is unlikely that the potential aqueduct would be significantly impacted by an earthquake.

Along northern San Joaquin Valley near the Delta, the potential alignment appears to be located approximately 10 miles east of the Greenville fault zone, which trends northwest through the city of Livermore and has segments along the fault that are considered active. The potential route does not cross the Greenville fault zone, but could be impacted or disrupted by any intense ground accelerations caused by earthquakes associated with the Greenville Fault. However, this scenario is unlikely, since only a small portion of the fault (approximately 4 miles long) has shown measurable displacement within the last 200 years.

The Delta-Chipps Island Disposal Alternative’s alignment does not appear to cross any major fault zones. However, the Delta-Carquinez Strait Disposal Alternative’s route would cross the Concord fault, which is an active segment of the Greenville fault zone and appears to extend beneath the Delta and beyond to the north (Figure G3-1). The Concord fault is estimated to have approximately 3.4 millimeters of horizontal fault creep on a yearly basis, with approximately 0.45 millimeter of uplift on the eastern side of the fault occurring in the same time frame. Recent studies of the fault indicate that the fault has caused approximately 65 feet of offset in the last 6,000 years. This amount of offset is unlikely to cause a significant impact to the Delta-Carquinez Strait Disposal Alternative’s pipeline. However, engineering measures should be conducted prior to construction to ensure that the yearly creep will not impact the pipeline over a 10- or 20-year period, depending on the estimated life of the pipeline. No evidence exists of catastrophic ground rupture associated with the Concord fault.

G3.3.2.4 In-Valley Disposal Alternative

The two types of land subsidence could impact the In-Valley Disposal Alternative, including pore space compaction and hydrocompaction. This alternative’s location is south and upgradient from the existing Drain. This alternative would use pumps to lift the water from the existing Drain to the reuse facilities. Land subsidence within this area could change the grade of the potential aqueduct, which will be used to convey the water to the reuse facilities. . In-depth geotechnical investigations would likely be required along the potential conveyance alignment for this alternative to evaluate the potential for subsidence of these sediments prior to the construction. In addition, topographic data could be used in connection with USGS historical benchmark data to determine the amount of subsidence in areas along the potential route and near the reuse facilities. The potential alignment should not be influenced by the oil extraction land subsidence, since it mostly occurs in southern San Joaquin Valley near Bakersfield.

G3.4 REFERENCES

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